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EFFECTS OF THE ELECTRICAL STIMULATION OF HUMAN
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The main task of the study was to prevent the disturbance of the functional state of the muscular system, lowering of the muscular tonus, and atrophy, under conditions of limited mobility with the aid of electrical stimulation.

It was assumed that the action of electrical stimuli on large muscle groups, according to the princple of the "local effect," formulated by Scherington, provides for a whole complex of reactions in them, including vascular reactions which are characteristic for natural motion and which take into account both the requirements of the muscles themselves as well as the entire organism. Thus, the maintenance of the functional state of the muscles could render no single positive result on their trophical system. An average positive effect could be expected from blood circulation and the occurrence of a number of metabolic processes (1,2,3). Electrical stimulation as a means of action on the vascular reactions is similar to the fact that while changing its intensity one can cause pressor or depressor reactions in the stimulated muscles (4).

In the first experiment, 12 young male volunteers were kept for 45 (sic) days under continuous bed rest in an antiorthostatic position at an inclination angle of 6° (head lower than legs). There were 4 subjects in three series of tests. In the first series 20 electrodes were used for electrical stimulation; 12 electrodes were used in the third series. Stimulations was done twice a day in the morning and in the evening six times a week. The stimulation session was increased gradually beginning with 15 minutes and, after a week, it lasted up to 30 minutes. The muscles of the spine, abdomen and lower extremities were stimulated. The stress value was close to the maximum arbitrary contraction. It was approximately 0.6 - 0.9 of its value.

Before the experiment, a specimen of muscular tissue was taken from the soleus muscle of the right leg of each subject by biopsy for morphological and histochemical studies. 30 days after the test began, specimens of the muscular tissue of the same muscle from the left leg of the same subjects and, in addition, specimens of the soleus muscle from 4 men serving as control and not subjected to any actions were taken. During histochemical study, a single specimen of muscle from the subjects of all the experimental groups and of the control group was mounted on a single cryostatic block holder. Thus, one slide showed 4 specimens of muscular tissue, which were subjected to a single treatment in conducting this or that histochemical reaction and later easily were submitted for comparative study. During biometric investigation, the cross sectional area of the fiber was determined with a planimeter.

In order to exclude the effect of biopsy on the functional state of the organism, physiological investigations were made: up to the experiment before biopsy, 15 days after the end of the experiment.

All subjects perceived electrical stimulations as an agreeable procedure. In spite of the long use of the electrodes, there were no inflammation reactions of the integuments.

The first 3-5 days of hypokinesia were most distressing to the subjects. Of the complaints heard, the most characteristic were: sensation of heaviness in the region of the head, headaches, dizziness in certain cases and spatial illusions. Reddening of the sclera and integument of the face was noted. Edema of the face of most of the subjects was maintained up the end of the experiment. These external signs associated with the redistribution of the blood were not observed in the first days after completion of the bed rest. Tolerance of the experimental conditions was better in subjects subjected to electrical stimulation.

The tonus of the shin and hip muscles was lowered and their perimeter was decreased in all subjects at the end of the experiment.

The degree of expression of these changes was most expressed in subjects of the control group. In particular, the hardness of the anterior tibial muscle in the control group decreased on the average by 21.2% while in the subject with electrical stimulations it was decreased by 11.5% (2nd series) and by 7.4% (third series). The perimeter of the shin muscle was reduced by 13% in the control group but in two series with stimulation it was 5.5% and 6.6% correspondingly. During study of the static endurance of the leg muscle there was observed a lowering of this index by 9.9% in the control series and, conversely, its increase by 51.6% and 36.2% correspondingly in the subjects with electrical stimulation. Additionally, the positive effect of stimulation was shown during measurement of muscle force. While conducting the test on a bicycle ergometer with a physical load of high intensity causing an increase of the pulse rate up to 170-180 beats per minute, there was no observable positive effect from electrical stimulation at once after the completion of the experiment, but it was observable during conducting this test 10 days after hypokinesia.

Immediately after completion of the bed rest regime, the orthostatic stability of all the subjects was decreased. In three subjects a syncope state was observed, one in the control group and two in the third series. In the 2nd series a higher tolerance of the orthostatic test was shown. Here there was no syncope states, the pulse rate increased considerably lower than in the control group, which was accompanied by a more stable and higher arterial pulse pressure.

Biometric study indicated that in all four subjects, being in a state of hypokinesia, a staticly (sic) reliable decrease in the volume of the red muscular fibers occurred in the soleus muscle and in two subjects there was a reliable decrease of the volume of the white muscular fibers, whereas in two other subjects the white muscular fibers did not change. In subjects in the state of hypokinesia and subjected to electrical stimulation (3rd series), the volume of muscular fibers either remained unchanged or increased, with the exception of only one subject in whom the volume of white fibers decreased although the red muscle fibers in him increased in volum. The positive effect of electrical stimulation was also seen in studyi . the muscle fibers of subjects of the 2nd series.

Thus, hypokinesia lasting 30 days leads to the development of atrophic processes in the soleus muscle, in large measure expressed in the red muscle fibers. Electrical stimulation of the muscle of individuals found in a state of hypokinesia prevents the development of atrophic processes both in the red and also in the white muscle fibers.

Histochemical studies of the oxylytic enzymes (succinate dehydrogenase, alpha-glycerophosphate dehydrogenase, beta-hydroxybutyrate dehydrogenase, adenosine triphosphatase) of muscular tissue permitted the establishment of a shift in the oxylytic metabolism. However in each subject the change in activity of the oxylytic enzymes, as a rule, bore its own special character in connection with which it was unusally difficult to evaluate the effect of electrical stimulation.

Electron microscopic data attest to the fact that in muscle fibers during hypokinesia, expressed structural changes occur in the contracting apparatus, expressed in the isolation of the myofibrills, their local lysis, in swelling and destruction of the stria.

During hypokinesia, in combination with electrical stimulation, tessellation of the ultrastructures of muscular fibers is observed. This relates to the forms and sizes of the mitochondria, density of the crista packing, the appearance of a large number of ribosomes and glycogen. In singular muscle fibers, necrotic sections were observed.

On the basis of the data derived, obtained during clinical observations of subjects, physiological and morphologial investigations, the opinion was formed on the fact that electrical stimulation of the muscles, as a method of non-specific training, can be prospective for the prophylaxis of a number of functional disturbances, analogous to those which inevitably occur in man in space flight. We surmise that the prophylactic effect of active muscle training can be strengthened if it will be combined with electrical stimulation of the muscles. Expecially as in space flight there are no serious limitations for the use of the two methods indicated. The prophylactic effect of physical training and electrical stimulation was observed in a special experiment. Just as in the previous experiment, nine subjects underwent seven weeks of bed rest, maintaining continuously an antiorthostatic position (head lower than legs). Six subjects daily completed work on a bicycle ergometer for 60 minutes daily, with an energy loss of 500 kcal while laying on their spine. Additionally, once a day the subjects themselves conducted electrical stimulation of the muscles of the spine, abdomen, and legs for 15 minutes. Three subjects were used as a control (hypokinesia without electrical stimulation). The main task of this experiment consisted in maintaining the initial stability of the cardio-respiratory system of man in relation to the physical load close to the limiting.

The physical work capacity of the subjects was studied in a background period, and later on the second and 25th days of the recuperation period. A test for maximum physical work was used as the functional load. After recording the initial indices, the subject in a sitting position pedaled a bicycle ergometer for 5 minutes at a constant power equal to 600 kg-m/min; later, beginning with 6th and each subsequent minute the load level was increased by 100 kg-m/min (the 7th minute - 800 kg-m/min; 8th minute - 900 kg-m/min; etc) until complete fatigue. The rate of pedal rotation was constant at 65 plus or minus 5 rpm. During the test, the following were recorded: time in which the subject was in a state to complete the increasing test (not considering the 5 minutes of stretching), the rate of heart contractions on an electrocardiogram with chest leads, and gas exchange on an automatic gas analyzer.

During the evaluation of the work capacity of the subjects, a large value was imparted to the maximum requirement of oxygen (max O_2, l/min) and its consumption per unit of weight (max O_2/kg,ml/kg/min). At this time this parameter is recognized as an integral index of the functional capacity of the cardio-respiratory system. It has been established in numerous experimental investigations (including our own) that with an increase in the level of training (physical work capacity) this index increases, but with a decrease, it falls.

As follows from the table presented, after the 49-day bed rest, the time in the course of which the subjects pedaled a bicycle ergometer in the control group decreased by 2 minutes 06 seconds but in the experimental group it rose by 77 seconds in comparison with the initial data. The frequency of cardiac contractions, with which the subjects of both groups completed the work on the bicycle ergometer was changed insignificantly, i.e. the stress of the cardiovascular system both in this and in other cases was approximately equal. Thus the maximum oxygen requirement in the experimental group in practically all the subjects rose (on the average by 0.21 l/min or by 8%) and in the control group it decreased (on the average by 0.32 l/min or by 13%). In calculations for unit body weight, the maximum oxygen requirement in the experimental group rose on the average by 3.6 ml/kg/min (i.e. by 10%) and in the control group it decreased by 4.3 ml/kg/min (i.e. by 12%).

This attests to the fact that in the experimental group the functional level of the cardio-respiratory system is completely maintained while in the control group it was considerably lowered.

Thus, the data presented offer the possibility to draw the conclusion that the use of electrical stimulations in combination with physical loads permit the maintenance of the physical work capacity of men in the course of even such long periods as a 49-day bed regime.

TABLE. INDICES OF THE MAXIMUM PHYSICAL WORK CAPACITY BEFORE AND AFTER A 49-DAY BED REST (BR)

Subjects	Time of work (min)		Maximum pulse rate (beats/min)		Maximum O_2 (1/min)		Maximum O_2/kg (ml/kg/min)	
	Before BR	2 days after BR	Before BR	2 days after BR	Before BR	2 days after BR	Before BR	2 days after BR
I	8,20	5,0[illegible]	I82	I80	2,40	2,I4	33,5	30,3
2	7,64	4,05	200	208	2,20	I,86	35,2	28,8
3	7,30	7,00	I82	I80	2,74	2,39	37,5	31,I
Average	7,28	5,22	I88	I92	2,45	2,I3	35,4	3I,I
4	7,27	9,05	I88	I88	2,5I	2,72	35,3	39,6
5	9,39	I0,30	I92	I95	2,75	2,67	39,7	39,2
6	8,32	[illegible],I5	I7[illegible]	I7[illegible]	2,46	2,35	33,2	37,9
7	9,I3	9,I2	I88	I90	2,72	3,04	37,2	4I,3
8	7,03	[illegible],2[illegible]	I7I	I76	2,I9	2,62	28,8	33,0
9	[illegible],40	8,40	I84	I85	2,33	2,84	37,5	40,5
Average	[illegible]	[illegible],I5	I84	I85	2,51	2,75	35,I	38,7

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